### 3.1.3.2 Geologic Structure

Geologic structures (folds, faults, etc.) are features that result from deformation of rocks after their original formation. The present-day geologic structure of the Great Basin, including the Yucca Mountain region, is the cumulative product of multiple episodes of deformation caused by both compression and extension (stretching) of the Earth's crust.

Major east-west crustal compression occurred periodically in the Great Basin between about 350 million and 65 million years ago (DIRS 151945-CRWMS M&O 2000, pp. 4.2-21 and 4.2-27). This compression moved large sheets of older rock great distances upward and eastward over younger rocks (for example, thrust faults) to produce mountains. During the last 20 million years, crustal extension has resulted in the pattern of elongated mountain ranges and intervening basins (DIRS 151945-CRWMS M&O 2000, pp. 4.2-27 and 4.2-28). Crustal extension has resulted in vertical, lateral, and oblique movements (Figure 3-9). By about 11.5 million years ago the present mountains and valleys were well developed (DIRS 104181-Scott and Bonk 1984, all; DIRS 101557-Day et al. 1998, all).

Figure 3-7 shows the bedrock geology at the Yucca Mountain site and Figure 3-8 shows geologic structure. Figure 3-10 shows the surface traces of faults and their characteristic northerly alignment.

The crustal extension during the last 20 million years fractured the crust along the generally north-trending normal faults. Some of the crustal blocks were downdropped and tilted by movement along their bounding faults (called block-bounding faults). The estimated total displacement along the major north-trending block-bounding faults during the last 12 million years ranges from less than 100 meters (330 feet) to greater than 500 meters (1,600 feet) (DIRS 151945-CRWMS M&O 2000, pp. 12.3-38 to 12.3-58).

Measurements of Quaternary (1.6 million years to present) displacement reported on these faults range from 0 to 6 meters (0 to 20 feet), with most displacement in the 1-to-2.5-meter (3.3-to-8.2-foot) range (DIRS 101929-Simonds et al. 1995, Table 2). Displacements along faults are characterized in terms of the amount of movement per seismic event. For the set of faults of primary significance to the Yucca Mountain site, these values range from 0 to 1.7 meters (0 to 5.6 feet) per event (Table 3-8).

Table 3-8 lists the characteristics of the faults that are important to an understanding of seismic hazards to the potential repository. The Solitario Canyon fault along the west side of Yucca Mountain and the Bow Ridge Fault along the east side are the major block-bounding faults that bracket the area under consideration for the proposed repository. The proposed repository has been configured so that there would be no block-bounding faults in the emplacement zone.

Between the major north-trending, block-bounding faults there are *intrablock* or *subsidiary faults*. One intrablock fault, called the Ghost Dance fault, is in the area of the proposed repository. The Ghost Dance fault has a near-vertical dip from the surface to the depth of the repository (DIRS 151945-CRWMS M&O 2000, p. 4.6-22). This fault crosses the Exploratory Studies Facility tunnel. There is no evidence of Quaternary movement along the Ghost Dance fault (Table 3-8). Within the repository block, there are many subsidiary northwest-trending faults with smaller displacements than the block-bounding faults (DIRS 104181-Scott and Bonk 1984, all). There is no clear evidence that displacements have occurred along these subsidiary faults during the last 1.6 million years (DIRS 101929-Simonds et al. 1995, all). One short northwest-trending subsidiary fault, called the Sundance fault, transects the potential repository area (Figure 3-10).

The faults described above are associated with well-defined fractures in the rock structure. In addition to these fault fractures where there is a displacement of the sides in relation to each other, there are also fractures along which no appreciable movement has occurred. These are called *joints*. In the Paintbrush

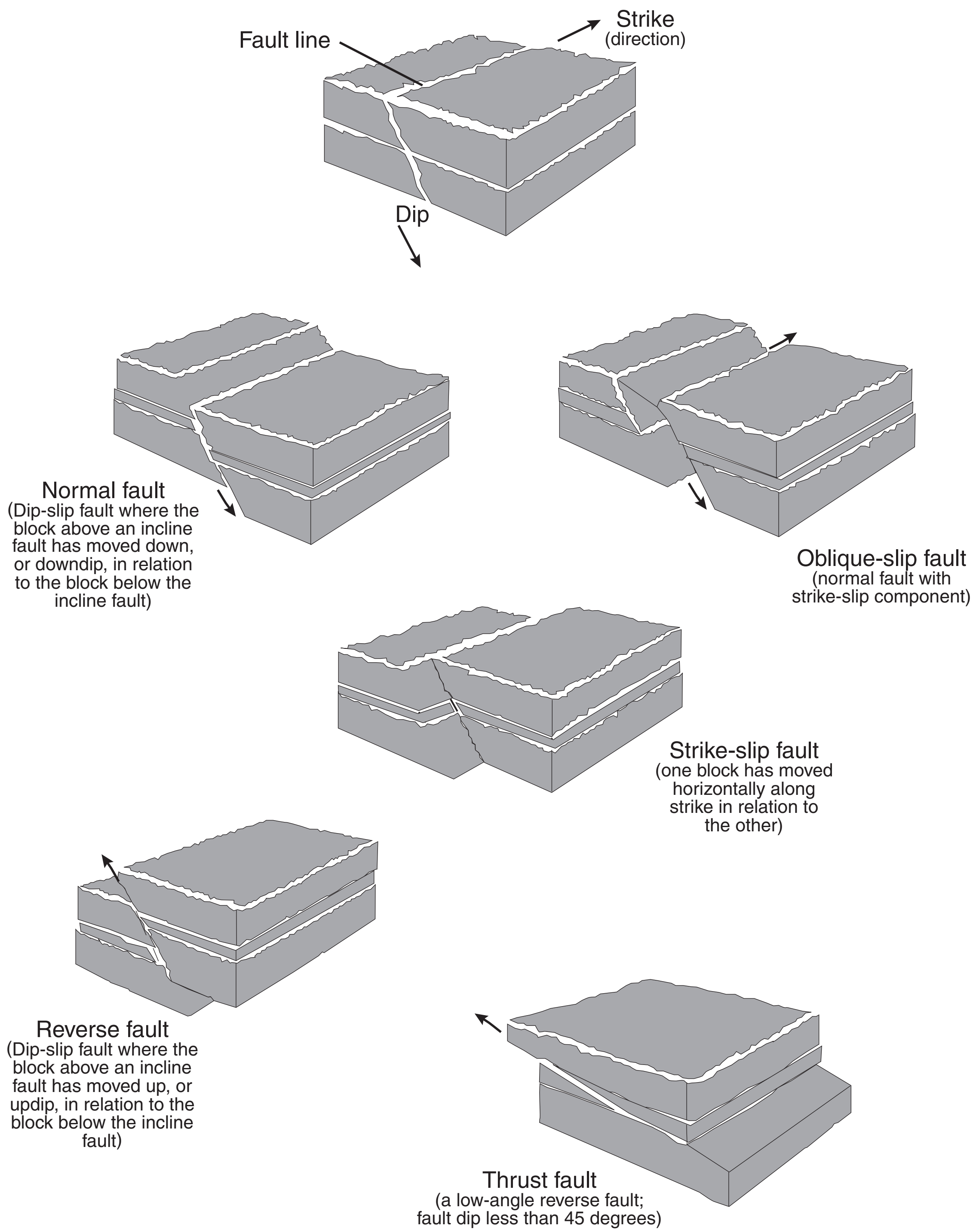


**Figure 3-9.** Types of geologic faults.

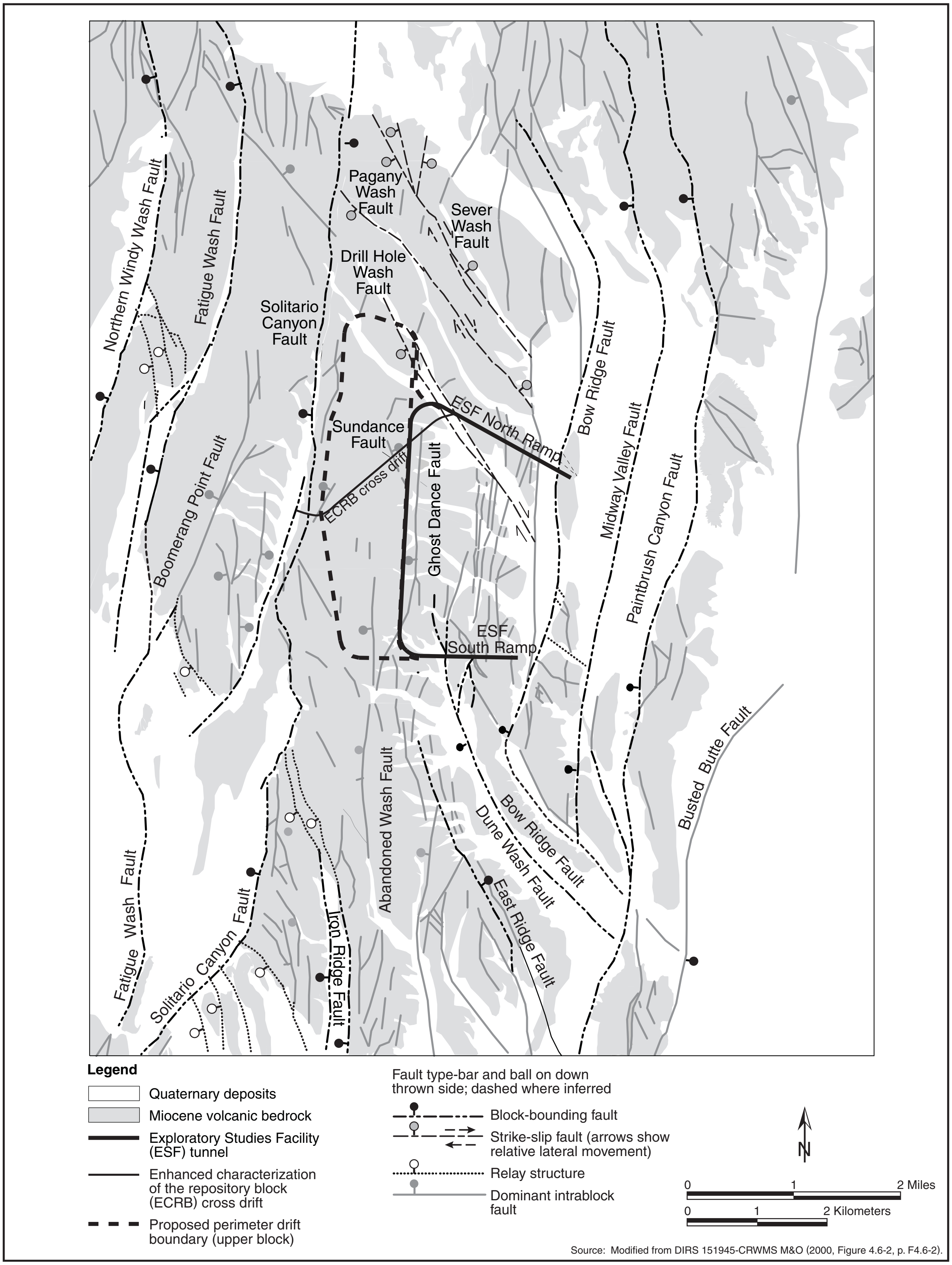


**Figure 3-10.** Mapped faults at Yucca Mountain and in the Yucca Mountain vicinity.

**Table 3-8.** Characteristics of major faults at Yucca Mountain.[a]

| Fault | Surface features | Evidence of Quaternary displacement | Displacement per event[b] (meters)[c] | Total displacement; type of movement | Fault length (kilometers)[b] and dip |
|---|---|---|---|---|---|
| Crater Flat fault zone (north and south fault zones) | North zone has 2 faults 300-600 meters apart, bedrock faults and scarps, subtle scarps and lineaments in alluvium, bedrock/alluvium fault contacts. | 3 of 3 trenches show multiple events; lineaments in alluvium, subtle scarps and fractures in alluvium. | 0 - 0.5, north, 0.1-0.2, south | Total displacement unknown; oblique, left-lateral, west side down. | 1 - 20 individual, 5 - 40 combined<br>70° west (north); 82° to 89° west (south) |
| Windy Wash fault[e] | Fault-line scarps in alluvium; bedrock/alluvium fault contacts; merges with Fatigue Wash fault. | 3 of 3 trenches show multiple ruptures; basalt ash in fault plane; fractures and scarps in alluvium | 0.7 | Less than 500 meters; mostly dip-slip, west side down | 3 - 35; 77° west to vertical |
| Fatigue Wash fault[e] | Bedrock and alluvial scarps; fault-line scarps, lineaments in alluvium; merges with Windy Wash fault. | 2 of 2 trenches show multiple ruptures; basalt ash in fault plane; fractures and scarps in alluvium. | 0.3 - 1.3 | 75 meters; oblique left-lateral, west side down. | 10 - 17; 73° west |
| Solitario Canyon fault[e] | Prominent fault-line scarp; discontinuous fault traces; subtle scarps in alluvium; southeastern splay is the Iron Ridge Fault. | 6 of 11 trenches show multiple ruptures; basalt ash in fault plane; fractures and scarps in alluvium. | 0 - 1.3 | Increases southward from 0 to >500 meters; mostly normal with minor oblique left-lateral, down on east at north end, down on west at south end. | 12.5 - 22; 72° west |
| Stagecoach Road fault | Prominent scarp and traceable faults in alluvium, merges with Solitario Canyon fault and (or) Paintbrush Canyon fault. | 2 of 3 trenches show multiple events; fractures and scarps in alluvium; basalt ash in faulted alluvium. | 0.4 - 0.7 | 400 to 600 meters; normal dip-slip to left oblique, west side down. | 4 - 5 73° west |
| Ghost Dance fault zone[f] | Bedrock fault in zone of subparallel minor faults and breccia zones. | None | None | Increases southward from up to 5 meters at north end and 12-15 meters in central portion; dip-slip, west side down. | 3 - 9; > 65° west |
| Bow Ridge fault[e] | Fault-line scarp along bedrock/alluvium contact; subtle lineaments; may merge along strike with Paintbrush Canyon fault. | 3 of 7 trenches show multiple ruptures; basalt ash in fault plane; fractures and scarps in alluvium. | 0.1 - 0.4 | 125 meters; oblique left-lateral, west side down. | 6-10; 65° to 85° west |
| Midway Valley fault[e] | None, fault located on basis of geophysical evidence. | None | None in late Quaternary | 40 - 60 meters; dip-slip, west side down. | 1 - 5; west[g] |
| Paintbrush Canyon fault[e] | Bedrock and alluvial faults, scarps, and lineaments; possibly merges along strike with Stagecoach Road fault. | 6 of 14 sites (10 trenches in Midway Valley and 4 exposures at Busted Butte) show multiple ruptures; basalt ash in fault plane; fractures in alluvium. | 0.06 - 1.7 | 250 - 500 meters; dip-slip and oblique left-lateral, west side down. | 10 - 26; 70° west |
| Northwest-trending faults[h] (not major faults) | Bedrock faults with local fault line scarps; most located by drilling and geophysical surveys. | None, with the exception of one trench across Pagany Wash fault showing absence of Quaternary displacement. | None (see column to left). | Undetermined; right-lateral to oblique right-lateral. (Except Dune Wash: 50-100 meters; normal, west side down.) | Undetermined; dip varies |

a. Source: Modified from DIRS 106342-Menges and Whitney (1996, Table 4.2.1) with data from DIRS 151945-CRWMS M&O (2000, pp. 12.3-38 to 12.3-58; Tables 12.3-8a, -8b, and -9; pp. T12.3-7 to T12.3-19).
b. Preferred estimate of surface displacement associated with a prehistoric earthquake.
c. To convert meters to feet, multiply by 3.2808.
d. To convert kilometers to miles, multiply by 0.62137.
e. Block bounding fault.
f. Intrabock fault.
g. The dip and direction of this fault are uncertain.
h. Subsidiary northwest tending faults, includes the Pagany Wash, Sever Wash, Drill Hole Wash, and Dune Wash faults.

Group (Tiva Canyon, Yucca Mountain, Pah Canyon, and Topopah Spring tuffs), joints are subdivided into three groups based on their generating mechanism and time of occurrence: early cooling joints, later tectonic joints, and joints due to erosional unloading (DIRS 151945-CRWMS M&O 2000, pp. 4.7-5 to 4.7-7). Each type of joint exhibits different characteristics with respect to its length, orientation, and connectivity. The cooling and tectonic joints have similar orientations (generally running north-south), but cooling joints include irregularly spaced horizontal joints as well. Joints due to erosional unloading are variably oriented but tend predominantly east to west, cross-wise to the cooling and tectonic joints. Tectonic joints occur throughout the Paintbrush Group and cooling joints are identified in each of the welded units. In general, the highest joint frequencies and connectivities occur in the units of the Tiva Canyon and Topopah Spring tuffs and the lowest occur in the nonwelded Yucca Mountain and Pah Canyon tuffs. Most joints, particularly cooling joints, are confined to specific rock units and do not cross unit boundaries. They do not generally form through-going features like faults. Geologic, geoengineering, and hydrologic aspects of fractures are discussed in detail in the Yucca Mountain Site Description (DIRS 151945-CRWMS M&O 2000, pp. 4.6-17 to 4.6-19, 4.7-5 to 4.7-7, 4.7-36 to 4.7-40, and 8.9-1 to 8.9-15).

DOE identified and described alternative tectonic models to explain the current geologic structure resulting from past tectonic processes and deformation events that have affected the Yucca Mountain site. These models are described in the *Yucca Mountain Site Description* (DIRS 151945-CRWMS M&O 2000, Section 4.3), and were considered by the experts in the Probabilistic Seismic Hazard Analysis (DIRS 100354-USGS 1998, all) discussed below. Computer models provide a means of integrating data on volcanism, deposition, and fault movement, and include a representation of the existing geologic structures and the processes that operate at depth. Tectonic models provide a basis for evaluating the processes and events that could occur in the future and potentially affect the performance of a repository. The DOE hazard assessments used models that are supported by data.

### 3.1.3.3 Modern Seismic Activity

DOE has monitored seismic activity at the Nevada Test Site since 1978. The epicenters of many earthquakes that the Southern Great Basin Seismic Network has located within 20 kilometers (12 miles) of Yucca Mountain do not correlate with mapped surface traces of Quaternary faults (DIRS 151945-CRWMS M&O 2000, pp. 12.3-17 and 12.3-18). This lack of correlation is a common feature of earthquakes, particularly those of smaller magnitude, in the Great Basin and elsewhere. Earthquakes in the Yucca Mountain region have focal depths (the point of origin of an earthquake below the ground surface) ranging from near-surface to about 5 to 12 kilometers (3 to 7 miles) (DIRS 151945-CRWMS M&O 2000, p. 12.3-18). The earthquake focal mechanisms are *strike-slip* to normal *oblique-slip* along moderately to steeply dipping fault surfaces. These focal mechanisms indicate the nature of the fault planes on which the earthquakes occur, as shown in Figure 3-9.

The largest recorded historic earthquake within 50 kilometers (30 miles) of Yucca Mountain was the Little Skull Mountain earthquake in 1992 (DIRS 151945-CRWMS M&O 2000, p. 12.3-7 and Figure 12.3-4, p. F12.3-4), which had a Richter magnitude of 5.6 (DIRS 151945-CRWMS M&O 2000, p. 12.3-18). This seismic event occurred about 20 kilometers (12 miles) southeast of Yucca Mountain, about a day after the magnitude 7.3 earthquake at Landers, California, 300 kilometers (190 miles) south-southeast of Yucca Mountain. The Little Skull Mountain event caused no damage at Yucca Mountain, although some damage occurred at the Field Office Center in Jackass Flats (DIRS 151945-CRWMS M&O 2000, p. 12.3-18) about 5 kilometers (3 miles) north of the epicenter.

#### *Seismic Hazard*

DOE based the design ground motion and fault displacement that could be associated with future earthquakes at Yucca Mountain on the record of historic earthquakes in the Great Basin, evaluation of